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Land Surface Temperature Measurements from EOS MODIS Data

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Abstract

A paper on the vicarious calibration of the MODIS Airborne Simulator (MAS) thermal infrared channels based on the MAS data and field measurement data acquired in the field campaign conducted in Mono Lake, California, on March 10, 1998, was published in the October issue of Applied Optics. The land-cover product from the University of Maryland was updated to its latest at-launch version in the product generation executive code PGE16 for the daily MODIS LST product. A thermo vacuum bottle and a temperature-controlled heating rubber are used to ensure the performance of the Heimann IR thermometer in the cold environment below freezing. A video transmitter/receiver set is used to store temperature images from an AGEMA IR camera in a video camcorder tape on the ground and then to write the images to a PC's hard disk at a speed higher than 22 frames/second. These improvements make it possible to hang the IR camera on a smaller tethered balloon to provide useful information of the LST temporal and spatial variations in the field campaigns that have been planned for the vicarious calibration of MODIS TIR channels and the validation of MODIS LST products. Numerical simulations have been initiated for the development of LST algorithms for the MODIS PM data.

Recently Published Papers

Z. Wan, Y. Zhang, X. Ma, M. D. King, J. S. Myers, and X. Li, "Vicarious calibration of the Moderate-Resolution Imaging Spectroradiometer Airborne Simulator thermal infrared channels", Applied Optics, Vol. 38, No. 30, pp. 6294-6306, 1999.

Z.-L. Li, F. Becker, M.P. Stoll, Z. Wan, and Y. Zhang, "Channel selection for soil spectrum reconstruction in 8-13 mu m region," J. Geophys. Res. - Atmos., Vol. 104, pp. 22271-22285, 1999.

Z.-L. Li, F. Becker, M.P. Stoll, and Z. Wan, "Evaluation of six methods for extracting relative emissivity spectra from thermal infrared images," Remote Sens. Environ., Vol. 69, pp. 197-214, 1999.

1. A MAS Vicarious Calibration Paper Published

A paper on the vicarious calibration of the MAS thermal infrared (TIR) channels based on the MAS data and field measurement data acquired in the field campaign conducted in Mono Lake, California, on March 10, 1998, was published in the October issue of Applied Optics (enclosed in Appendix). The significance of this study is shown not only by giving results comparable with those from previous studies based on comparisons with High Resolution Interferometer Sounder (HIS) data and giving results for more TIR channels but also by demonstrating the advantages of using high-elevation sites under dry atmospheric conditions as vicarious calibration sites. For such calibration sites, well calibrated high spectral resolution airborne instruments are not necessary as long as ground-based instruments can provide accurate spectral surface-leaving radiance or accurate surface temperature and spectral surface emissivity, and atmospheric temperature and water vapor profiles at reasonable accuracies. Without requiring a flight of a well calibrated airborne instrument of high spectral resolution for each ground-based vicarious calibration activity, it will be easy to schedule the calibration field campaigns and to conduct a field campaign at a lower cost. Hence it will be possible to conduct more small-scale vicarious calibration field campaigns at different sites in order to evaluate the calibration accuracy of the MODIS TIR channels over a wide range of scene temperatures.

2. Update of the MODIS LST Product Generation Executive Code (PGE16)

The previous version (v2.1.25) of the at-launch MODIS LST code (PGE16) was recently upgraded to version v2.2.1. The new version code was tested on the PI's SCF (science computing facility) and delivered to the MODIS Science Data Support Team (SDST).

Besides fixing the metadata problems found in the tests performed on the MODIS Data Processing System (MODAPS) at GSFC, for example, duplicated granule pointers in the output files, the major change in the new version of the PGE16 code is the update of the at-launch land cover product from version 2.1 to its latest version (version 3). In version 3 of the University of Maryland at-launch land cover product, there are totally 328 tiles. We made a statistical analysis of grid types in terms of sea/land masks in all 328 tiles and found that there is no single land grid in 14 tiles as shown in Table I. The first column in Table I shows the horizontal and vertical id numbers of the tile, columns 2-9 show the numbers of grids in land, coastline, shallow inland water, ephemeral, deep inland water, shallow, moderate, and deep ocean, respectively. The last column shows the number of grids with _FillValue 255 in science data set (SDS) Land_Cover_Type_1. Within the 14 tiles, only the first three tiles (with id numbers h01v07, h01v08, and h02v08) contain coastline grids. Coastline grids without a single land grid mean that there are islands with a size smaller than one square km each in these tiles. In the remaining 11 tiles, there is no any grid in land, coastline, or inland water but grids in shallow, moderate, and/or deep ocean. Because the MODIS LST product does not deal with ocean grids, these 11 tiles will not be used in the PGE16 processing. Therefore, only 317 land tiles will be used in the the PGE16 processing. Look-up table land_tile_tbl.h was modified according to the locations of the 317 land tiles. Look-up table band_emis.h was also modified to adapt to the land type classification used in the latest at-launch land cover product.

TABLE I. Statistics of grid types in 14 tiles in which there is no single land grid.

tile id	land grids	coastal lines	shallow	ephemeral	deep	shallow	moderate	deep	filled grids
			inland water			ocean			
h01v07	0	29	0	0	0	272	0	1434756	4943
h01v08	0	506	0	0	0	2479	0	1437015	0
h02v08	0	613	0	0	0	2417	17	1436953	0
h03v05	0	0	0	0	0	0	9	908415	531576
h03v08	0	0	0	0	0	9	15	1439976	0
h04v05	0	0	0	0	0	20	19	1423956	16005
h11v01	0	0	0	0	0	4790	1184	0	1434026
h12v16	0	0	0	0	0	170	3686	313887	1122257
h13v16	0	0	0	0	0	47	8632	786370	644951
h14v15	0	0	0	0	0	49	418	1439533	0
h24v01	0	0	0	0	0	5938	0	0	1434062
h24v10	0	0	0	0	0	3862	31732	1404406	0
h30v04	0	0	0	0	0	2	7	864323	575668
h31v04	0	0	0	0	0	6	4	216124	1223866

3. Improvements of the IR Instruments for MODIS Calibration/Validation

3.1. Custom improvements made for the Heimann IR thermometer

One lesson learned from our previous field campaigns is that the Heimann IR thermometer does not work in cold environments. Although the low limit of its operating range of ambient temperature is specified as 0 °C, it would not perform appropriately as the ambient air temperature comes down to approximately 3 °C. We made the following custom improvements to resolve this problem. The metal body of the thermometer is wrapped with a silicone rubber heater and attached with a custom-designed temperature-control circuit based on a tiny digital thermometer and thermostat device (DS1620) from Dallas Semiconductor. The thermometer body temperature is measured with the built-in sensor of the circuit. We can input temperature settings into the circuit with a PC. The rubber heater is powered with a 12V battery. The current to the rubber heater will be set on by the circuit if the thermometer body temperature is lower than the temperature setting. The circuit will turn off the current if the thermometer body temperature is equal to or higher than the temperature setting. Then we put the wrapped thermometer into a thermo vacuum bottle. An experiment was made to demonstrate the performance of the improved thermometer: the temperature setting in the circuit was set to 15°C, an external thermistor was used to measure the thermometer body temperature, the thermometer was placed in a refrigerator, a black painted aluminum sheet was placed in front of the thermometer and another thermistor was attached to the sheet for temperature measurements. Figure 1 shows the thermometer body temperature, and the comparison between aluminum temperature values measured by the Heimann thermometer and the thermistor. In this experiment, the rubber heater was not in active in the period of 14 hours. The thermometer body temperature was kept above 15°C because of the heat generated by the thermometer itself during operating and the good insulation provided by the thermo vacuum bottle. A 24V battery powered the Heimann thermometer above an appropriate level for about 13 hours and 40 minutes. The difference between temperature values given by the Heimann thermometer and the thermistor is less than 1°C, which is approximately the error of the thermistor in such a cold condition. This indicates that with these custom improvements the Heimann IR thermometer performs well in the cold environment below -10°C.

3.2. Custom improvements made for the AGEMA IR camera

A major issue in our field campaigns since 1995 is that we do not have enough data to determine the range of uncertainties in the comparisons between the LST measured by field instruments and the LST retrieved from airborne and/or satellite data due to the spatial variation in LST. The field-of-view (FOV) of ground-based TIR instruments ranges from 25cm to 50cm, while the MAS pixel size is 50m and the pixel size of MODIS TIR channels is 1km or larger. Therefore, it is critical to know the spatial variation in LST at the scales from several centimeters to at least 50m, at an accuracy good enough for the calibration/validation purpose. We purchased an IR camera (THERMOVISION 570) from AGEMA Infrared Systems in late 1997 and received the recalibrated IR camera in 1998. The detector used in this IR camera is a focal plane array of uncooled microbolometer with 320 x 240 elements in the spectral range of 7.5-13μm. The FOV of the camera is 24° by 18°. There are four options of temperature ranges available for user selection. Normally, the -20 to 120°C range is suitable for our applications. The accuracy specification is ±2°C. In its standard mode, the image data can be stored on a PCMCIA hard disk card at a highest rate of one frame per second or lower rates. We checked the accuracy by placing the camera in front of a blackbody at temperature 25°C and storing 100 image frames. It was found that the accuracy of a single image is not good enough for our calibration/validation purpose. It is necessary to make an average image from more than 100 images. This IR camera takes about two minutes to store 100 images of a target scene even without considering the time to store images of blackbodies at 2-3 different temperatures for its accurate calibration. Such a speed is too slow for our calibration/validation purpose because there may be significant changes in the scene temperature during the period of two minutes. This IR camera can be upgraded to a high speed model (57 frames per second) with a special interface and a specialized PC at approximately 60% of the original price of the IR camera. We do not want to take this approach because we prefer to upgrade the IR camera into a lightweight system with common components priced for the large commercial market in order to take the advantage of rapid advances in the PC industry.

One option is to use a PC video card to grab temperature images from the AGEMA IR camera at a higher speed. After an image acquisition card, PCI-1411, from National Instruments is installed on a PC based on Intel Pentium II 300 MHz processor and a Ultra ATA hard disk drive, 12 images can be stored on the hard disk each second. The speed of storing images is increased to 22-24 frames per second when the image acquisition card is installed on a new PC based on Intel Pentium III 550MHz CPU and equipped with a high speed Ultra2 SCSI disk drive. The speed may be increased further on a PC equipped with a Ultra3 SCSI disk drive.

In order to get an appropriate field of view (FOV) for the AGEMA IR camera, we need to place it on a platform at a reasonable height above the ground. If the IR camera is placed on a fixed tower, its FOV will be decided by the height of the tower. For example, if the tower height is 50m, the IR camera has a FOV of about 21m by 16m when it looks down in the nadir direction. If the IR camera is hung on a tethered balloon at a height of 250m above the ground, the IR camera has a FOV of about 100m by 80m. Tethered balloons are quite inexpensive and easy to carry and transport. The net lift of a 10 ft. diameter ball-shape balloon filled with 524 cu. ft. of helium at 1000 feet above sea level is 24.7 lbs. After considering the weights of tether lines and a structure which fixes the IR camera in a secured condition, the net lift for the IR camera and other accessories will be no more than 10 lbs. at best. So a 10 ft. diameter balloon cannot carry the AGEMA IR camera (5 lbs.) and a notebook PC for storing the data. If we carry helium in cylinders each containing 100 cu. ft. of helium, we need at least five cylinders to fill up a 10 ft. diameter balloon. It may be difficult to transport more cylinders of helium to some remote areas. Helium supplies may be also very expensive in some places. One better solution will be to just place a small lightweight transmitter by the side of the IR camera on the balloon and to receive the images on the ground. We purchased a video transmitter/receiver set from Eye-witness. This unit utilizes 900 Mhz wireless technology and has a transmit range of up to 1000 feet. The transmitter has a size of 2"

H x 1.25" W x 0.5" D, runs 1 to 2 hours on a single 9V battery. By connecting the receiver to a VCR or video camcorder, we can store the temperature images from the AGEMA IR camera in a video tape on the ground. The images on the video tape can be written to a PC's hard disk in the post-processing stage. With the video transmitter/receiver set, it is possible to hang the IR camera on a smaller tethered balloon to provide useful information of the LST temporal and spatial variations in the field campaigns that have been planned for the vicarious calibration of MODIS TIR channels and the validation of MODIS LST products.

Field campaigns planned for 2000 are shown in Table II. A vicarious calibration field campaign over the area of Mono Lake, CA, is planned for March/April 2000. MAS/AVIRIS flights have been requested for this campaign. A vicarious field campaign over Uyuni Salt Flats, Bolivia, is being planned for May/June 2000. A field campaign over Railroad Valley, NV, and the area of Mono Lake, CA, is scheduled for July 2000 for the MODIS LST validation. MAS/AVIRIS flights have been requested for this campaign. Collaboration will occur during the ASTER's calibration/validation field campaign over Mauna Loa, Hawaii, in April-June 2000. MASTER flights have been requested during the PACRIM-II deployment. We may join the field campaign of SAFARI 2000 and to conduct ground-based TIR measurements over Makgadikgadi Salt Pans, Botswana, in August 2000, depending on the overguide fund we requested. Close collaboration with the ASTER team and other groups will be kept for future MODIS LST validation activities, and new opportunities for collaboration in the international efforts to validate LST at the global scale will be pursued.

TABLE II. Field campaigns planned for 2000.

time	site	purpose	airborne sensor(s)	field measurements
March/April 2000	area of Mono Lake, CA	vicarious calibration	MAS, AVIRIS	LST, radiance
May/June 2000	Uyuni Salt Flats, Bolivia	vicarious calibration		LST, radiance
July 2000	Railroad Valley, NV	LST validation	MAS, AVIRIS	LST, radiance
April-June 2000	Mauna Loa, Hawaii	calibration/validation	MASTER	LST, radiance

4. The Development of LST Algorithms for the MODIS PM Model

The refinement and development of the MODIS LST algorithm for the MODIS PM model was initialized. The LST product PM-1 MOD11comb will contain Levels 2 and 3 land surface emissivity and temperatures retrieved through the combination of PM and AM/Terra MODIS data so that the retrieved surface temperature with a better diurnal feature will be more suitable for various applications. In the early post-launch period the PM-1 MOD11adv product will include Levels 2 and 3 land surface emissivity and temperatures retrieved by an advanced LST algorithm that also corrects the effects of thin cirrus clouds and aerosols with inputs from MODIS atmospheric products.

Numerical simulations have been made for the development of LST algorithms for the MODIS PM model. A close collaboration with Paul Menzel's atmospheric profile retrieval group at The University of Wisconsin-Madison was established in the development of new LST algorithms. Our research has been focused on the simultaneous retrieval of surface temperature and emissivity, and atmospheric temperature and water vapor profiles from simulated MAS data over wide ranges. A paper on this research has been submitted to Applied Optics.

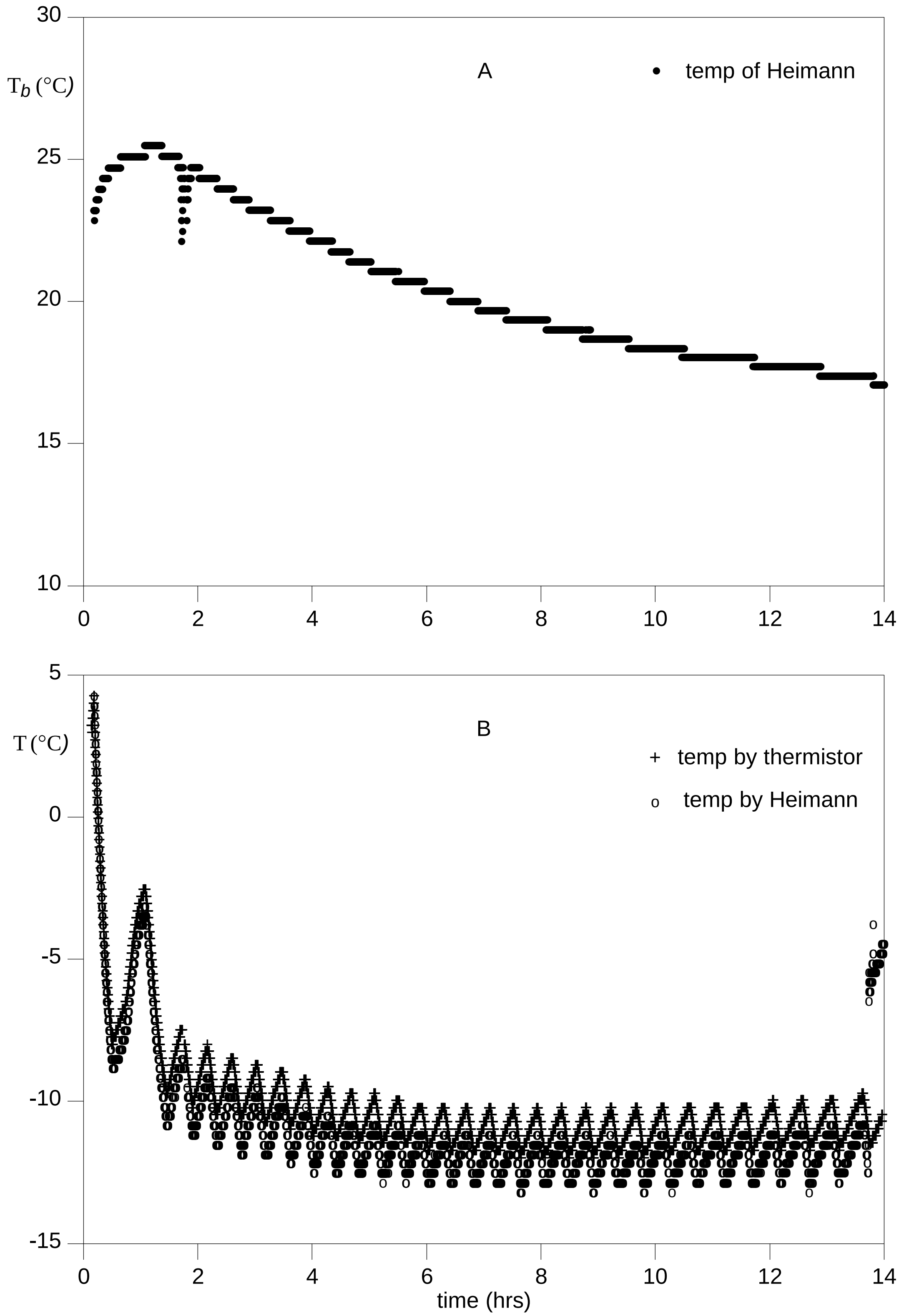

Figure 1, Body temperature of a Heimann IR thermometer (A), and the comparison between temperature values given by Heimann and thermistor in a refrigerator (B).

Appendix

Vicarious calibration of the Moderate-Resolution Imaging Spectroradiometer Airborne Simulator thermal infrared channels

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